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DEVELOPMENT AND PERFORMANCE EVALUATION OF CRUSHER CUM SCRAPER FOR THE PREPARATION OF JAGGERY GRANULES

DILIP PAWAR1, PRAKASH UNDE[2] & GAJANAN NEVKAR[3]

[1]*Scientist, Agro-produce processing division, ICAR-CIAE, Bhopal, Madhya Pradesh, India*

[2]*Ex. Professor and Head, Department of Agricultural Process Engineering, MPKV, Rahuri, Maharashtra, India*

[3]*Assistant Professor of APE, Regional Sugarcane and Jaggery Research Station, Kolhapur, Maharashtra, India*

ABSTRACT

A crusher cum scraper for making jaggery granules was developed and its performance on recovery of jaggery granules of was evaluated. U trough vessel with centrally mounted helical scraping ribbons, distributing ribbons, primary crushing bars, crushing peddles and side scrapers constitute the working mechanism of machine. The effect of three machine parameters viz., operational speed, time of operation and feed rate on recovery of jaggery granules below a size of 3 mm was studied. Crystallized jaggery chunks were prepared from sugarcane juice by heating it at elevated striking temperature (124-126°C) and increasing pH of juice up to 6.4. The prepared jaggery chunks were crushed, stirred and scraped in developed machine to convert mass it into jaggery granules. Results revealed that the machine parameters significantly affected the recovery. Maximum recovery of 76.52% was recorded at an operational speed of 20rpm, time of 8min and feed rate of 2kg/min. The lowest granule recovery was observed at higher levels of all the three parameters because of combined effect of over crushing of jaggery chunks and it's skipping from primary crushing bars.

KEYWORDS: Jaggery Granule Recovery, Crusher Cum Scraper, Performance, Helical Ribbons Peddles & Bars

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INTRODUCTION

Jaggery is a traditional sweetener made by concentration of sugarcane juice to a specific striking point temperature. It has a vital importance in human diet because of its medicinal importance and health benefits over refined sugar. Jaggery industry is still at cottage level because of different technological limitations. India produces world's more than 70 per cent of jaggery (Rao et al. 2007). Uttar Pradesh, Karnataka, Maharashtra, Tamil Nadu and Andra Pradesh, these five states contribute 80-90 per cent of India's total jaggery production. However the utilization of sugarcane for jaggery production has declined from 54 per cent in 1980-81 to 15 per cent in 1013-14, (Gangwar et al.2015). The India's total sugarcane produced i.e. 300 Mt is used as 53% for white sugar, 36% for jaggery and khandsari, 3% for fresh juice and 8% for seed cane (Singh et al. 2011).

Jaggery can be made in three forms viz., solid, liquid and granular jaggery or powdered jaggery. Out of its total production in India, only 20 per cent is in granular form while remaining 80 per cent jaggery is in solid and liquid form, (Rao et al. 2007). Jaggery in its granular or powdered form has number of advantageous over the lumped jaggery. Less moisture content leading to is extended storage life is one of the important advantages. Better solubility, easy handling and handy packaging also appeals the entrepreneur and consumers to have it in granular form.

However the technology of granular jaggery has not been standardized which is commercially viable. Few researchers has reported the process of granular jaggery. Increased pH of juice up to 6.2-6.4 with addition of lime and increasing the striking point temperature to 120-122°C are the findings of previous research, (Sridevi, 2008). Similar remarks have been reported by Singh *et al.* (2013). After boiling up to striking point the material is taken on aluminum tray and scraped with hand scraper to convert mass onto granules. Drying, sieving and packaging are the further unit operations. An invention on mechanized granulator for jaggery granules has been invented by Rao *et al.* (2015). It consists of development of granulator in which the semisolid jaggery syrup was scraped and stirred. The discharged mass was then dried and crushed in hammer mill to form jaggery granules. Some local producers of jaggery granules are crushing the jaggery mass with long glass bottles or wooden roller for granule preparation. The process of making granules manually is tedious, time consuming and unhygienic.

A research work was therefore undertaken to develop a machine named crusher cum scraper for making jaggery granules. The machine was developed and its performance was evaluated on percent recovery of jaggery granules of size below 3 mm.

MATERIALS AND METHODS

Crusher cum scraper for making jaggery granules was developed and fabricated at department of Agricultural Process Engineering, MPKV, Rahuri and tested for its performance on percent recovery of jaggery granules of size less than 3mm at experimental scale jaggery making setup of RSJRS, Kolhapur. The granules of size less than 3 mm are of better quality, (Nath et al. 2015) and have good market acceptability.

Sample Preparation

Crystallized jaggery chunks were prepared by boiling sugarcane (Co 92005) juice with some modifications in regular jaggery making process. The striking point was increased up to 124-126°C and pH of juice was adjusted to 6.4-6.5 to enhance crystallization. After preparation of jaggery, the semisolid syrup was allowed to cool with simultaneously stirring at small intervals so as to form jaggery chunks of 3-7cm size. Seeding was carried out with addition of dry seeds as nuclei and hence to enhance process of crystallization. This techniques has been reported effective in increasing the crystallization, (Suwansri *et al*. 2009; Aider *et al*. 2007). The prepared chunks were crushed, scraped and stirred by internal mechanism of developed machine to form jaggery granules. Trials were carried out with a batch of 7kg sample of jaggery chunks. Formed jaggery granules were sieved manually and recovery of was calculated as its weight percent of size less than 3mm.

Development of Crusher cum Scraper

A machine named crusher cum scraper for making jaggery granules was developed for the preparation of jaggery granules (Figure 1). The principle mechanisms of the machine were crushing, scraping and stirring. The main constructional components of the machine are U trough working vessel, central mechanism with crushing bars, scraping ribbons and peddles mounted on common shaft. The machine parts in contact with granules were made of food grade material SS-304 while other parts were of mild steel. The power transmission mechanism consists of electric motor (3-phase, 3-hp), gear box, pulleys, couplings, bearings and shaft. Leonard, (1998) and Mearly (1998) also invented a mixer with similar mechanism of scraping ribbon for mixing and scraping the food material.

U-Trough Working Vessel

U-trough working vessel as shown in figure 2, was made of SS sheet of thickness 2.5mm. The bottom of vessel was kept semicircular with a radius of 191mm. Upper portion was kept rectangular with length, width and height as 535mm, 432mm and 36.5mm respectively. The total volume of working vessel was 0.088m^3 with 0.06m^3 of upper rectangular portion and 0.028m^3 of lower semicircular portion. Similar kind of ribbon blender studying its mixing performance have been reported by Fernando *et al.*(2008).

The two sides of vessel were closed with side closures of size 432mm x 550mm. U-trough vessel and side closures were joined with hexagonal headed nuts and bolts of standard size. A transparent cover made of fiber glass was hinged to one side of U trough which was closed during operation of machine and also to protect the internal mechanism from contamination. The working vessel was provided with opening of size 100mm x 80mm for discharge of granules at bottom.

Discharge Gate with Pivot Mechanism

The sliding gate was operated with pivot mechanism to close and open the central discharge. A pivot mechanism consists of circular platform of diameter 150mm provided with handle and pitman shaft connected to gate.

Internal Mechanism

The internal mechanism (Figure 3) consists of helically mounted scraping ribbons, crushing bars and peddles. This mechanism was mounted on central shaft of diameter 35mm and length 760mm. The shaft was mounted on standard bush bearings provided at either side.

Helical Ribbons

The scraping ribbons made of stainless steel with cross section 25mm x 5mm were mounted helically on the central shaft with support bars 12mm diameter.

Two ribbons were fixed opposite to each other. The arrangement of ribbon is in similarity with the ribbons of all the ribbon blender studied by Fernando et al. (2008) and Myerly (1998). The outer diameter of the ribbons was kept as 370mm. The helix angle and angle from top were kept as 54° and 234°, respectively. Length before bending of the ribbon was 902mm.

Primary Crushing Bars

The primary crushing bars were first to crush jaggery chunks. The stainless steel bars of 6mm diameter were fixed on the helical ribbons in transverse directions. Seventeen bars with a uniform spacing of 15mm were fixed transversely on edge of ribbons. The bars were provided to one side only leaving another side open for the purpose of cleaning and to avoid clogging. Three bars 6mm in diameter were fixed across the crushing bars with uniform spacing. This was to capture the jaggery chunks for crushing after feeding on the bars.

Crushing Peddles

The four crushing peddles were provided for final crushing of jaggery chunks. A larger peddle with length of 373mm and bending angle of 36° was fixed with a clearance of 3mm between peddle and vessel wall. Another peddle of length 210mm and bending arc of 88mm was fixed adjacent to larger peddle with a clearance of 5mm. Two uniforms

peddles of length 170mm and bending arc of 113mm were fixed opposite to each other. They were joined on central shaft with SS bars of 12mm diameter. Two bars were used to fix one peddle. These bars were welded to shaft after fixing it in the holes made on shaft. The clearance between these peddles and vessel was kept as 3mm.

Distributing Ribbons

Two distributing ribbons of 25mm x 5mm cross sectional size were provided from inside of crushing bars. The purpose is to distribute jaggery chunks uniformly throughout the internal mechanism. These ribbons were fixed in opposite direction as one clockwise and one anticlockwise. The outer angle, helix angle and angle from top were 322mm, 47° and 124°, respectively. The length before bending was 430mm.

Side Scraper

The side scrapers, made of SS flat 25mm x 4.5mm, were provided at either side in opposite direction to prevent accumulation of material at sides. They were fixed on the central shaft with a notch made on it. Small cut of 47.5mm x 6mm was made to flat plate in order to have free rotation of side bushes.

Feeding Hopper

The feeding hopper was made of stainless steel metal of thickness 2.5mm. The shape of hopper was designed as per the feeding suitability. Some portion of hopper is rectangular and rest is triangular in shape contributing total volume of $0.16m^3$. The overall dimensions of rectangular portion are 465mm x 300mm x 80mm. An opening of 165mm x 80mm was provided for easy feeding of jaggery chunks. The feeding was done manually with intermittent fall on primary crushing bars. Arrangement was made to fix feeding hopper on U-trough vessel with back side supported on the platform of gearbox. Hopper with supporting leg was fixed on gearbox platform by standard hexagonal headed nuts and bolts. The front end of hopper was supported on vessel itself.

Power Transmission Mechanism

The power transmission mechanism consists of electric motor, gear box, pulley, belt, coupling, bearing and shaft. Power was transmitted to internal mechanism through these different components. A 3-phase, 3-hp electric motor was used, having standard operating speed of 1440rpm. This speed was reduced to required speed of 20rpm using standard gear box having size reduction ration of 30:1. Power was transmitted to gear box through these pulley-belt drive mechanism. Three levels of speed were achieved by changing the pulleys as per required speed. Two standard bush bearings with plummer blocks were provided at either side of the shaft. A frequency derive was provided in order to have reversible speed. A starter was fixed to vertical platform of mild steel. A knob was provided to starter to change the direction of rotation.

Supporting Frame

All the parts of machine were mounted on supporting frame made of different sections of mild steel. Four C-angles of size 75mm x 40mm and 6mm thickness were fixed vertically with side closures (432mm x 510mm) at either end of the working vessel. Another two C-angles of 280mm length were welded horizontally to connect vertical C-angles. L-sections of size 50mm x 50mm and 6mm thickness were fixed vertically and horizontally to pedestal power transmission mechanism on it. Two L-sections of length 430mm were fixed vertically and three of the length 285mm horizontally. A stiffener of size 77mm x 200mm made of mild steel was provided on either sides to fix standard plummer blocks with

required hexagonal headed nuts and bolts.

RESULTS AND DISCUSSIONS

Performance Evaluation of Crusher cum Scraper

The developed crusher cum scraper for making jaggery granules was evaluated for its performance and the effect of different machine parameters viz., operating speed, operating time and feed rate on percent jaggery granule recovery was studied. Trials were conducted by changing the different levels of dependent parameters. Machine was run with double pass for increasing the recovery of granules with a batch of 7 kg jaggery chunks. The material was discharged from machine and sieved to calculate the percent recovery of jaggery granules below 3mm.

Effect of Operating Parameters of Crusher cum Scraper on Recovery of Jaggery Granules

The recovery of jaggery granules was studied at three operating parameters of crusher cum scraper viz., speed, time and feed rate. The operating speed levels were kept as 10 rpm, 20 rpm and 30 rpm. The time of operation and feed rate levels were kept as 4, 8 & 12 min and 2, 3 & 4 kg/min.

The individual and combined effect of these parameters was studied and analyzed at 5% level of significance (Table 1 to 4). All the three factors showed significant effect on recovery of jaggery granules. The paired effect of each of two parameters also reported significant effect on recovery except the combination of time of operation and feed which was found non-significant. The granule recovery was also affected significantly with combined effect of operating speed, time and feed rate at 5 % level of significance. The coefficient of variance and grand mean of analyzed data is 0.919 and 57.466, respectively.

Effect of Operating Speed on the Recovery of Jaggery Granules

The internal crushing, scraping and stirring mechanism of the machine was mounted on central shaft of 35 mm OD, supported by bearings at either side. The effect of rotating speed of this assembly on granule recovery was studied and the results are presented in table 1. The operating speed showed significant effect on percent granule recovery. The maximum recovery was found at operating speed of 20 rpm followed by 10 rpm. The recovery was found lowest at 30rpm and this was because of over crushing of jaggery material leading to formation of aggregated chunks. The increased operating speed also increased temperature because of increased friction. The observation was in agreement with Juan and Fernando, (2015) who reported that the temperature of final blend increases with increase in time of blending. Increased temperature had negative effect of granule formation causing dough formation of material. Rao et al. (2015) reported 76 rpm of jaggery granulator, however the final crushing was carried out in hammer mill to obtain granules of mass mean diameter of 1000 µm. They also seen significant effect of moisture content of feed on particle size distribution of granules and optimized 9.02% d.b. moisture content. The moisture content of jaggery chunks used in present study was also 9.5% d.b. which in agreement findings of Rao et al (2007).

Effect of Time of Operation on the Recovery of Jaggery Granules

Preliminary trials conducted by operating the machine for different times as 4min, 8min and 12min and its effect on recovery of jaggery granules was studied (Table 2). The recovery of jaggery granules found to be maximum as 61.66% for 8 minutes run time of machine. There was no considerable different on recovery when operated at 4 and 8 min, but increased operating time to 12 min, significantly the recovery to 50.165. This was the result of over crushing of jaggery

chunks. The material was likely to form a dough like and swell if machine was operated for higher time. It was also found that the jaggery material was converted into dough like consistency due to over crushing when machine was operated at extended time. The clogging was also observed when time of operation was exceeded 8 min.

Effect of Feed Rate on the Recovery of Jaggery Granules

The chunks of jaggery were kept in feeding hopper and fed on primary crushing bars manually. The care was taken to feed the material at center of crushing bars to minimize the skipping of chunks from the sideways of bars. Trials were conducted at three different feed rates as 2, 3 and 4 kg/min and recovery of jaggery granules below 3mm size was calculated as shown in table 3.

The feed rate showed significant effect on granule recovery. Increase in feed rate reduced the recovery to a minimum of 55.645%. This reduction was because of skipping of the jaggery chunks from either side of primary crushing bars. The skipped large size material was very difficult to capture in crushing mechanism and therefore the recovery was observed to be less. The maximum recovery of 59.20% was reported at 2 kg/min feed rate.

Effect of Operating Speed and Time on Recovery of Jaggery Granules

The combined effect of operating speed and time on recovery of jaggery granules was found significant, depicted in Figure 4. The granule recovery was found maximum of 75.40% at 20 rpm operating speed and 8min time of operation. The recovery was decreased to 67.21% at same operating speed but decreased time to 4 min. At an operating speed of 10 rpm it was found higher when operated for 8 min. Increased levels of speed and time drastically reduced the recovery to 38.08%. This is over crushing effect at higher speeds and higher times. Prolonged periods of high speed mixing will lead to segregation of mixture, (Yeow et al. 2011). Thus 20 rpm for 8 min is best combination for maximum recovery of jaggery granules.

Effect of Operating Speed and Feed Rate of Jaggery Granules

The operating speed and feed rate also significantly affected the recovery of jaggery granules. Figure 5 depicts that at all the levels of feed rate the recovery was maximum at an operating speed of 20 rpm. It was recorded maximum of 69.25% at 2 kg/min and 20 rpm followed by 3 and 4 kg/min. comparatively the effect of operating speed was more on the recovery. The maximum and minimum recovery at 10rpm and three feed rate levels were 59.43% and 55.55%, respectively. All the three feed rates at 30 rpm reported minimum values compared to 10 and 20 rpm speed levels. The lowest recovery among all the combinations was found as 44.77%. This lowest recovery of because of combined negative effect of skipping the jaggery chunks and over crushing of material at higher speeds.

Combined Effect of Operating Speed, Time and Feed Rate on Recovery of Jaggery Granules

The combined effect of operating speed, time and feed rate reported significant effect on the recovery of jaggery granules. Table 4 interprets the recovery at different combinations of these parameters at 5% level of significance. The recovery of jaggery granules was recorded maximum as 76.52 % at 20 rpm operating speed, 8 min time of operation and 2 kg/min feed rate. The combination recording lowest recovery of 34.75 % was 30rpm operating speed, 12 min time and 4 kg/min feed rate. For all the operating speeds and time, the feed showed no considerable variation in jaggery granule recovery. In combination of feed rate and operating speed, time of operation showed significant variation in recovery values. The recovery ranged from 74.34 % to 76.52 % for all three levels of feed rate at 20 rpm operating speed and 8min

time of operation. Thus for maximum recovery of jaggery granules the developed crusher cum scraper can be operated at 20rpm for 8 min with 2 kg/min rate of feeding.

CONCLUSIONS

A crusher cum scraper for making jaggery granules was developed, fabricated and tested for the recovery of jaggery granules. Internal working mechanism consists an assembly of helical scraping ribbons, distributing ribbons, primary crushing bars, crushing peddles and side scrapers mounted on centrally rotating shaft. The assembly was surrounded by a U trough vessel of 0.088 m^3 total volume. Crystallized jaggery chunks were prepared with slight modification in jaggery making process and were used as raw feeding material to crusher cum scraper. Jaggery granules were formed with a maximum recovery of 76.52% at 20 rpm operating speed, 8 min time of operation and 2 kg/min feed rate. The developed machine is thus suitable for large scale production of jaggery granules over the tedious, time consuming and unhygienic manual process of making jaggery granules.

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APPENDICES

Tables

Table 1: Effect of Operating Speed on the Recovery of Jaggery Granules

Operating Speed (rpm)	Mean Recovery of Jaggery Granules (%)	SE (5% S)
10.0	57.499	0.102
20.0	67.984	0.102
30.0	46.915	0.102

Table 2: Effect of Time of Operation on the Recovery of Jaggery Granules

Time of Operation (min)	Mean Recovery of Jaggery Granules (%)	SE (5% S)
4.0	60.568	0.102
8.0	61.664	0.102
12.0	50.165	0.102

Table 3: Effect of Feed Rate on the Recovery of Jaggery Granules

Feed rate (kg/min)	Mean recovery of Jaggery Granules (%)	SE (5% S)
2.0	59.200	0.102
3.0	57.552	0.102
4.0	55.645	0.102

Table 4: Combined Effect of Operating Speed, Time and Feed Rate on Recovery of Jaggery Granules

<table>
<tr><th>Operating Speed (rpm)</th><th>Time of Operation (min)</th><th>Feed Rate (kg/min)</th><th>Mean recovery of Jaggery Granules (%)</th></tr>
<tr><td rowspan="9">10.0</td><td rowspan="3">4.0</td><td>2.0</td><td>58.21</td></tr>
<tr><td>3.0</td><td>57.18</td></tr>
<tr><td>4.0</td><td>55.57</td></tr>
<tr><td rowspan="3">8.0</td><td>2.0</td><td>66.27</td></tr>
<tr><td>3.0</td><td>64.23</td></tr>
<tr><td>4.0</td><td>61.77</td></tr>
<tr><td rowspan="3">12.0</td><td>2.0</td><td>53.82</td></tr>
<tr><td>3.0</td><td>51.13</td></tr>
<tr><td>4.0</td><td>49.32</td></tr>
<tr><td rowspan="8">20.0</td><td rowspan="3">4.0</td><td>2.0</td><td>69.05</td></tr>
<tr><td>3.0</td><td>67.37</td></tr>
<tr><td>4.0</td><td>65.20</td></tr>
<tr><td rowspan="3">8.0</td><td>2.0</td><td>76.52</td></tr>
<tr><td>3.0</td><td>75.33</td></tr>
<tr><td>4.0</td><td>74.34</td></tr>
<tr><td rowspan="2">12.0</td><td>2.0</td><td>62.18</td></tr>
<tr><td>3.0</td><td>61.58</td></tr>
</table>

		4.0	60.28
30.0	4.0	2.0	59.09
		3.0	57.69
		4.0	55.76
	8.0	2.0	47.45
		3.0	45.25
		4.0	43.81
	12.0	2.0	40.22
		3.0	38.21
		4.0	34.75

***** SE(m) =0.3050,

***** CD (5%)=0.8628

Figures

Figure 1: Pictorial View of Crusher cum Scraper

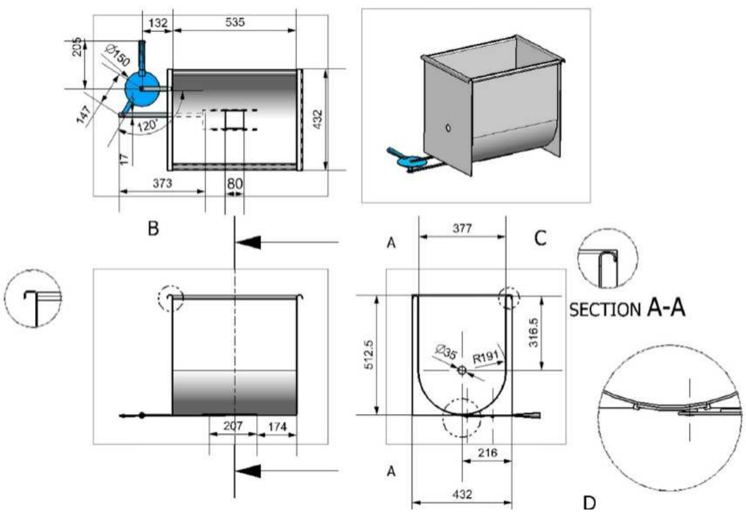

Figure 2: U-Trough Working Vessel

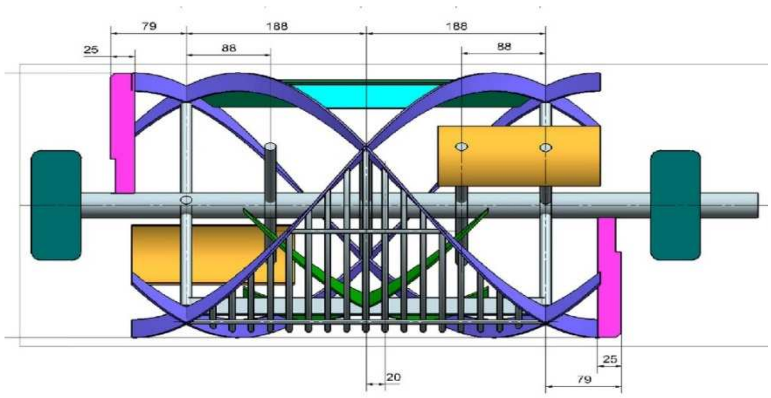

Figure 3: Internal Crushing Mechanism

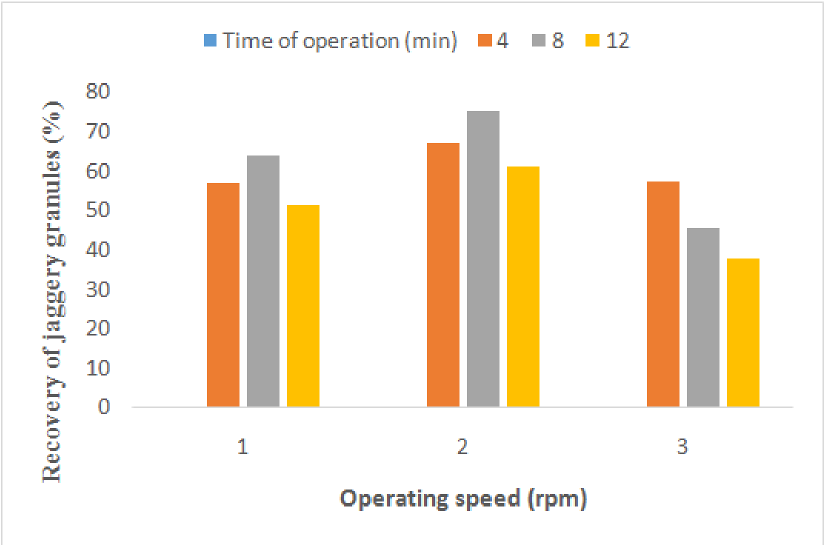

Figure 4: Recovery of Jaggery Granules at Different Operating Speeds and Time

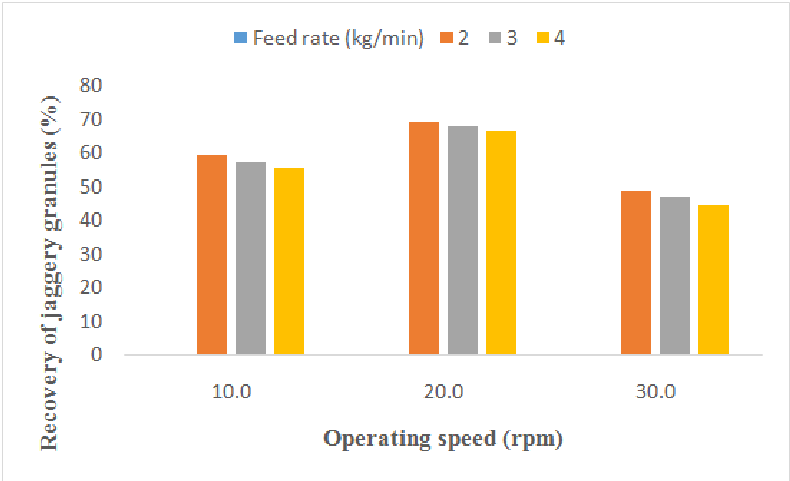

Figure 5: Recovery of Jaggery Granules at Different Operating Speeds and Feed Rate